CHAPTER 8
X-RAY PRODUCTION

ELECRON TARGET INTERACTION

Kinetic Energy
- The energy of motion
- *Symbol:* KE
- *Unit: J*
- *Formula:* KE = ½mv^2

1 keV = 1.6 x 10^{-16} J

Projectile Electron
- Electrons travelling from cathode to anode
- It interacts with the orbital electrons or nuclear field of target atoms
- *Three Effects:*
  - The production of heat
  - The formation of characteristics x-rays
  - The formation of bremsstrahlung x-rays

Anode Heat
- *Reasons:* constant excitation & return of outer-shell electrons
- Increases directly with increasing x-ray tube current & kVp

Efficiency of X-ray Production
- It is independent of the tube current
- It increases with increasing kVp

Characteristic Radiation
- It is emitted when an outer-shell electron fills an inner-shell void
- An interaction with the inner-shell of a target atom
- *Energy:* very specific

Only the K-characteristic x-rays of tungsten are useful for imaging!

K X-rays
- X-rays resulting from electron transition to the K shell

L X-rays
- X-rays resulting from electron transition to the L shell

This type of x-radiation is called characteristic because it is characteristic of the target element!

Bremsstrahlung Radiation
- It is produced when a projectile electron is slowed by the electric field of a target atom nucleus
- An interaction with the nuclear field of a target atom
- "*slowed down radiation"*
- It results from braking of projectile electrons by the nucleus
- *Energy:* all or none

High-Energy Bremsstrahlung X-ray
- It results when the projectile electrons loses all its KE & simply drifts away from the nucleus

Low-Energy Bremsstrahlung X-ray
- It results when the projectile electrons are barely influenced by the nucleus

In the diagnostic range, most x-rays are bremsstrahlung x-rays!

X-RAY EMISSION SPECTRUM

Spectrum
- Graphic representation of the range over which a quantity extends

Discrete Spectrum
- It contains only specific values

Continuous Spectrum
- It contains all possible values

X-ray Emission Spectrum
- It can be graphed as the number of x-rays for each increment of energy in keV

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Characteristic X-ray Spectrum

- A plot of the frequency with which characteristic x-rays are emitted as a function of energy

Characteristic x-rays have precisely fixed (discrete) energies and form a discrete emission spectrum!

Bremsstrahlung X-ray Spectrum

- It extends from zero to maximum projectile electron energy
- *Greatest Number of X-rays Emitted:* 1/3 of the maximum energy
- *Shape:* the same for all x-ray imaging system
- *Maximum Energy (keV):* equal to kVp operation
- *Number of X-rays:* decreases rapidly at very low energies

Bremsstrahlung x-rays have a range of energies & form a continuous emission spectrum!

Maximum x-ray energy is associated with the minimum x-ray wavelength (λ_{min})

FACTORS AFFECTING THE X-RAY EMISSION SPECTRUM

Integration

- A process that determines the total number of x-rays emitted
- Adding the number of x-ray emitted at each energy over the entire spectrum

Effective Energy/Quality of X-ray Beam

- *Higher:* the farther to the right of a spectrum

Intensity/Quantity of X-ray Beam

- *Higher:* the larger the area under the curve

FACTORS THAT AFFECT THE SIZE & RELATIVE POSITION OF X-RAY EMISSION SPECTRA

Factors	Effect
Tube Current	Amplitude of spectrum
Tube Voltage	Amplitude & position
Added Filtration	Amplitude, most effective at low energy
Target Material	Amplitude of spectrum & position of line spectrum
Voltage Waveform	Amplitude, most effective at high energy

Effect of mA and mAs

- A change in mA or mAs results in a proportional change in the amplitude of the x-ray emission spectrum at all energies

Four Principal Factors Influencing The Shape of X-ray Emission Spectrum

- Low-energy electrons interact to produce low energy x-rays
- Successive interactions of electrons result in the production of x-rays with lower energy
- Low-energy x-ray are most likely to be absorbed by the target material
- Added filtration preferentially removes low-energy x-rays from the useful beam

Effect of kVp

- A change in kVp affects both the amplitude & the position of the x-ray emission spectrum
- A change in kVp has no effect on the position of the discrete x-ray emission spectrum

Rule of Thumb

- It states a 15% increase in kVp is equivalent to doubling the mAs
    - *Purpose:* to obtain a given OD on the radiograph
    - It does not double the x-ray intensity
- *40% increase in kVp:* doubling the output intensity (not necessary)

In diagnostic range, a 15% increase in kVp is equivalent to doubling the mAs!

Added Filtration

- It reduces x-ray beam intensity while increasing average energy
- It absorbs low-energy x-rays
- Hardening of the x-ray beam
- *Characteristic Spectrum:* not affected

Effect of Added Filtration

- It results in an increase in the average energy of the x-ray beam with an accompanying reduction in x-ray quantity

Effect of Target Material

- Increasing target atomic number enhances the efficiency of x-ray production & the energy of characteristic & bremsstrahlung x-rays
- *Discrete Emission Spectrum:* shifts to the right with an increase in target Z
- *Continuous Emission Spectrum:* increases slightly in amplitude (high-energy side) with an increase in target Z

Voltage Waveforms

- Half-wave Rectification
- Full-wave Rectification
- Three-phase/six-pulse
- Three-phase/twelve-pulse
- High Frequency

Effect of Voltage Waveform

- As the voltage across the x-ray tube increases from zero to its peak value, x-ray intensity & energy increase slowly at first & then rapidly as peak voltage is obtained

Because of reduced ripple, operation with three-phase power or high frequency is equivalent to an approximate 12% increase in kVp or almost a doubling of mAs over single-phase power!

CHANGES IN X-RAY BEAM QUALITY & QUANTITY PRODUCED BY FACTORS THAT INFLUENCE THE EMISSION SPECTRUM

An increase in	Result in
Current (mAs)	An increase in quantity. No change in quality
Voltage (kVp)	An increase in quantity & quality
Added Filtration	A decrease in quantity. An increase in quality
Target Atomic Number (Z)	An increase in quality & quantity
Voltage Ripple	A decrease in quantity & quality